Physics: Frightful, But Fun

Pupils' and Teachers' Views of Physics and Physics Teaching

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ABSTRACT: There is widespread concern for the situation of school physics regarding recruitment, contents, teaching methods, etc. In this study based on questionnaire and focus group data, we explore how upper secondary pupils and teachers perceive physics as a subject, how they experience physics instruction, and how physics compares to other subjects.

Our study shows that pupils find physics interesting, but difficult and work-intensive; formalistic in nature, but still describing the world and everyday phenomena. Pupils express that "exotic" topics like astrophysics are closer to their life-world than mechanics etc. Whereas teachers complain about pupils' poor mathematics skills, pupils do not see this as a major problem. Physics instruction is still dominated by traditional content knowledge and seems to attract and reward pupils with this orientation. Pupils have a relatively weak understanding of the central role of experiments in science. Generally, pupils appear conservative in their views on teaching and learning; however, they would like stronger emphasis on qualitative and pupil-centred approaches.

Based on our findings, we suggest that an upper secondary physics education preparing pupils for tomorrow's society should be characterized by variety, both within and among courses, integration of mathematics in the physics courses, more pupil-centred instruction, and a stronger emphasis on knowledge in context. *Sci Ed* **88:**683–706, 2004

INTRODUCTION

Physics: Recruitment and Literacy

In many western countries there is a concern that the number of young people pursuing scientific and technological careers is too small to secure future needs for scientific and

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technological competence (Drury & Allen, 2002; Jørgensen, 1998). The situation appears particularly grave for physics (EPS, 1999; Institute of Physics, 2001), and efforts have been launched in a number of countries to turn the trend (Drury & Allen, 2002; European Space Agency, 2002; Institute of Physics, 2002). A separate, but related concern is the need to develop and maintain a scientifically literate population (AAAS, 1989, 1993; Millar & Osborne, 1998; NRC, 1996; Sjøberg, 2002; UNESCO, 2002). There is a concern in the physics community that physics struggles to attract attention and to change a largely negative public image (EPS, 1999).

In a recruitment context, girls represent a special challenge since they are under-represented in physics education on all levels in most countries (Drury & Allen, 2002; Mullis et al., 1998; National Science Board, 2002). Many explanations have been suggested to account for this, such as unfavourable learning environment, priorities relating to self-identity and roles, social influence factors, etc (Baker & Leary, 1995; Jones, Howe, & Rua, 2000; Labudde et al., 2000; Warrington & Younger, 2000).

In the efforts to meet the concerns of physics literacy and recruitment (including the improved recruitment of girls), school physics plays a key role. Thus, it is essential to understand how pupils in general and girls in particular perceive physics as a subject and how they experience physics teaching.

Curriculum Development and Trends in Physics Education

During recent years, educational reform projects have been launched for school science in Western countries. The concern for scientific literacy has been emphasized in projects such as "Project 2061" (AAAS, 1993) in the USA, the course "Science for public understanding" in Britain (Nuffield Foundation, 2002), and in research programs like PISA (Programme for International Student Assessment) (OECD, 2001).

Sjøberg (2002) noted "a general weakening of the traditional academic influence on the organization of the school curriculum and its content," and he listed a number of features that seem to be prominent in innovation projects: More attention to cultural, historical and philosophical aspects of science, more emphasis on the nature of science and science processes, emphasis on knowledge in context, more attention to key ideas in science at the expense of details, and so on. A prominent feature of the reform initiatives is the claim that science education should include knowledge *about* science as well as *in* science (Driver, Newton, & Osborne, 2000; Millar & Osborne, 1998; Ryder, 2001). The argued need for knowledge *about* science is closely linked to the claim that pupils should be taught the nature of science (Duschl, 1990; Lederman, 1992).

However, the intended curriculum is one thing; the implemented curriculum—what goes on in the classroom—may be another, and the attained curriculum—what cognitive and affective outcome pupils are left with after schooling—yet another (Goodlad, 1979). Eisner (2000) pointed out that what goes on in the classroom is in great part determined by the forms of evaluation employed—"what we test, we teach." In order to reform school physics with a view to recruitment and literacy, the written curriculum as well as its interpretation and implementation are of interest.

Restrictions to Change

In order for curriculum innovations to be effective and lead to the desired results, a number of factors are important. Geelan (1997) noted how teacher, pupil, parent, and administrator attitudes to appropriate roles for teachers and pupils may impede changes towards instruction forms that favour active learning. Tobin and McRobbie (1996) identified four "cultural myths" supported by teachers and pupils which they interpreted as impeding curriculum

reform efforts. Tobin, Mc Robbie, and Anderson (1997) investigated discursive practices in a high school physics classroom and found that in addition to the teacher's view of learning and instruction, there were also other belief sets that shaped the enacted curriculum. These related to time being scarce, content coverage being a primary concern, and students needing to be prepared for examinations.

Carlone (2003, p. 307) described "the conundrums associated with (. . .) enacting a 'science for all' within and against the 'academic', 'rigorous,' and 'elite' sociohistorical constructions of science" and noted that physics is a discipline whose boundaries are among the most tightly guarded of all the sciences. She showed how "prototypical physics" (physics envisioned as difficult, hierarchical, objective, etc.) is maintained and reproduced in an allegedly "reformed" physics course despite reform efforts, and she saw this as undermining the goals of a more inclusive physics. Information about pupils' and teachers' attitudes and about processes in the classroom are therefore an essential part of the background for successful implementation of reforms.

Research into Pupils' Understanding, Motivation, and Learning in School Physics

A large number of studies have documented pupils' understanding of various science topics and their "alternative conceptions" (DiSessa, 1993; Mullis et al., 1998; Pfundt & Duit,1994; Robitaille & Beaton, 2002; Viennot, 2001), and research related to physics has been prominent within this research tradition.

Interest, goals, and motivation have been identified as important for learning and academic performance (see for instance Hidi & Harackiewicz, 2000). Nolen (2003) found correlations between learning environment, motivation, learning strategies, and achievement among high school pupils. Classrooms focused on understanding and independent thinking positively predicted pupils' satisfaction with learning. Studying physics pupils' experience of physics instruction and their attitudes to the subject are therefore of interest when working to improve physics education and make it palatable for a greater variety of learners.

The relationship between physics and mathematics in upper secondary school has concerned a number of scholars (Carson, 1999; Gill, 1999; Orton & Roper, 2000). Whereas some point to lack of mathematical skills as a major impediment to physics understanding (Orton & Roper, 2000), others hold that it is the "translation" from a physical situation to the formalized language of mathematics that represents the real challenge (de Lozano & Cardenas, 2002; Dolin, 2002).

Experiments are a central characteristic of physics as a science, and the experimental side of science is one of several characteristics used by Lederman (1999) to define the nature of science (NOS). Ryder, Leach, and Driver (1999) showed how some students involved in open-ended empirical work did not appreciate the purpose of data collection in terms of model evaluation. Leach (1999) pointed out that many pupils and students are not able to evaluate the logical implication of data for knowledge claims, and recommended that pupils and students should be more explicitly introduced to the model-like nature of much scientific knowledge and the ways in which predictions are generated and observations are evaluated in terms of standard theories. Séré (2002), after a study of the objectives and conduct of labwork in seven European countries, recommended that a limited number of objectives should be selected for each lab session.

Physics in Norwegian Upper Secondary School

Norwegian pupils meet physics as part of an integrated science course throughout compulsory school (grades 1–10) and in the first year of upper secondary school (grade 11).

Because of teachers' competence profile, especially in lower grades, physic topics are not as visible in the implemented curriculum as the other topics of the science curriculum.

Norwegian upper secondary education (grades 11–13) is voluntary, but more than 95% of all 16–19-year-olds are enrolled. Upper secondary education comprises a variety of strands of study; a main division runs between the various vocational strands and the general theoretical strand preparing pupils for higher education in academic disciplines. Roughly 40% of all 16–19-year-olds attend the general theoretical strand. Altogether, ca. 12% of the age cohort choose physics as one of 2–3 subjects of specialization in grade 12 and ca. 7% in grade 13. Both courses fill five lesson hours weekly during the whole school year. In the course curricula, the grade 12 course is described as a more qualitative and "literacy-oriented" course, whereas the grade 13 course is described as more formalistic with more use of mathematics, preparing pupils for higher education in science or technology.

Since the early 1980s, the Norwegian upper secondary physics curriculum has been relatively "modern" in the sense that it includes modern physics topics (quantum physics, relativity, astrophysics, etc.) and also STS aspects as well as historical and philosophical dimensions.

Exams have an impact on what goes on in the classroom (Eisner, 2000). For the grade 13 physics course, the final exam is administered by the Ministry of Education and is the same for all pupils. During recent years there has been a tendency for the exams to include more open questions where pupils have to choose how to analyze the problem and define conditions.

The proportion of Norwegian youth taking physics to the highest level is relatively small in international comparison; however, those who do take physics reach a remarkably high level of understanding as measured in the TIMSS survey (Mullis et al., 1998).

Norwegian physics teachers are a relatively homogenous group. The typical physics teacher is 54 years old, male, and well educated (5–6 years of university education majoring in physics or closely related subjects). However, many of them lack competence in some "modern physics" topics. During the implementation of the current curriculum (from 1997), the Ministry of Education initiated an in-service training course for physics teachers. Apart from this, there has been no compulsory professional development for teachers, but in-service courses are offered by the physics departments at universities.

Aims of This Paper

In this paper, we present findings from a study of Norwegian pupils and physics teachers in upper secondary school. Questions to be explored are the following:

1. How do physics pupils and teachers perceive physics as a subject?
2. How do physics pupils and teachers experience physics instruction?
3. How do physics pupils compare to other pupils in their view on their subject of specialization?

Findings will be discussed in light of curriculum development, with a view to improving scientific literacy and increasing the number of students in physics-related careers.

METHODS

Questionnaire Study

Questionnaires were administered to random samples of grade 12 and grade 13 pupils taking physics as a subject of specialization. Sampling was done by asking every upper

TABLE 1
Overview of Respondents

Respondent Group	# Responses	Estimated Response Rate (%)	Females (%)
Grade 12 physics pupils	1141	70	33
Grade 13 physics pupils	1051	70	29
Physics teachers	342	50	11
Grade 12 pupils regardless of subject of specialization	1487	70	52

For pupils, the response rate refers to the number of responses in proportion to the number of administered questionnaire sheets. For teachers, the response rate is the number of responses in proportion to the estimated number of teachers in the whole population.

secondary school in Norway to select the first seven physics pupils in the alphabet from grade 12 and grade 13, respectively. In the same way, questionnaires were administered to a random sample of *all* grade 12 pupils in the general theoretical strand of upper secondary education. In the latter questionnaire, pupils were asked to indicate which of their 2–3 subjects of specialization they regarded as the most important one to them personally, and to answer questions with this subject in mind. In this way it was possible to compare physics pupils' perception of their subject with other pupils' perceptions of their respective subjects.

Questionnaires were also sent to all physics teachers in every upper secondary school in Norway. Table 1 shows an overview of the respondent groups.

Since the pupils are random samples of their respective populations, it is possible to generalize our results for the pupils to the populations with the caution that the response rates are not 100%. The teacher respondents are not a random sample and the results are therefore strictly valid only for the group of persons that actually responded, though we have no reason to believe that respondents differed in relevant ways from nonrespondents. Results regarding pupils are presented with uncertainties in the Results section and significance tests are applied where appropriate. A significance level of 95% is applied. For results regarding teachers, uncertainty and significance estimates are not applicable.

The questionnaires contained a mixture of open and closed questions. The closed questions had a common format with a Likert scale from 1 to 5. Some questions were the same across all respondent groups; others were specific to each respondent group.

Responses to closed questions were analyzed quantitatively using the statistics program SPSS. Responses to open questions were categorized, coded, and then subjected to statistical analysis as above. Approximately 10% of the responses were coded independently by two researchers, and an inter-rater reliability of 85% was found. Since each response on the open questions could consist of several statements and be coded into one or more categories, inter-rater reliability was calculated as the ratio of agreements to the number of statements actually coded into a category. Thus, "agreements" that a statement did *not* fall into a category, were not counted.

Focus Group Study

When the quantitative study had yielded preliminary results, a focus group study was conducted with grade 12 and 13 physics pupils. A focus group is a form of group interview where 6–8 persons discuss a topic under the direction of a moderator (Morgan, 1998a; Stewart & Shamdasani, 1990). Focus group studies may be used for a range of purposes

(Folch-Lyon & Trost, 1981); in the present study, focus groups were used to complement the quantitative data and gain increased insight into students' thoughts, feelings, and motivations.

Participants were recruited from 7 upper secondary schools in southeastern Norway. These schools were regarded as typical in terms of size and socioeconomic characteristics. Two physics teachers in each school were asked to recruit pupils from their respective classes. The teachers were instructed to choose pupils who had different abilities and attitudes to physics and who were willing and able to express their opinions. The sampling of the focus group pupils may therefore be characterized as both accidental and purposive (Ary, Jacobs, & Razavieh, 1996; Judd, Smith, & Kidder, 1991).

Eight focus group sessions were conducted with a total of 54 participants. Groups were segmented according to gender, since participants then were expected to be more relaxed and willing to share perceptions (Horner, 2000). Four groups were held with grade 12 pupils and four with grade 13 pupils. Previous research suggests that theoretical saturation is achieved after three to four focus groups (Morgan, 1998b). This was verified for the four boys' focus groups in the present study: no new codes were formed during the analysis of the fourth group, indicating that theoretical saturation had been achieved.

Focus group sessions lasted for about 90 min, during which the moderator guided participants through the issues of discussion. An assistant moderator was present during all sessions, taking notes and attending to practical matters. Sessions were audiotaped with the permission of the participants and were transcribed in their entirety.

Transcripts were analyzed qualitatively by inductive coding of units of meaning (Miles & Huberman, 1994). The program ATLASti 4.1 for Windows was used for organizing the material and providing easy retrieval. The material was reread several times and interpretations were modified and refined until a consistent account was reached (Krueger, 1998). Clustering of topics and interpretations were done in view of our research questions. This process led to a set of 80 codes.

The strength of focus groups is that they enable a range of views to be elicited. Pupil quotes presented in the next section may be chosen because they represent a common tendency found among respondents; however, quotes from single participants may also be chosen if they represent an interesting approach and contribute to showing the range of views present among participants.

RESULTS AND DISCUSSION

Physics: Hard, But Interesting

A general feature of physics pupils' description of their subject is that physics is regarded as difficult and with a high workload, but also interesting. We compared the views of grade 12 pupils (having chosen physics, social science, and English, respectively, as their most important subject) on their subject of specialization.

Figure 1 shows that physics pupils, to a larger extent than english and social science pupils, regard "their" subject as difficult, having a high workload, and fast progression through the curriculum. Similar findings have been reported by, for instance, Drury and Allen (2002) and Woolnough (1994). However, physics pupils also to a great extent describe their subject as interesting and the teaching as good. In this respect they are in line with the social science pupils, whereas english pupils are somewhat less satisfied.

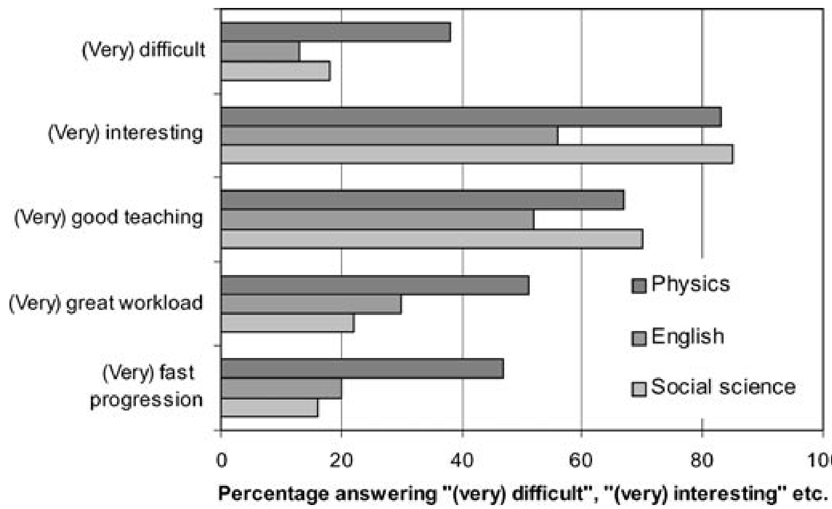

Figure 1. Grade 12 pupils' (having physics, english or social science, respectively, as their most important subject) rating of their most important subject of specialization. Columns show the proportion of pupils who rated each aspect as 4 ("difficult," "interesting,"..) or 5 ("very difficult," "very interesting,"..) on a 5-point scale. Uncertainty is ca. 6% points.

Should these findings be interpreted to mean that physics is inherently more difficult than other disciplines, or is the level of school physics—for historical or other reasons—unjustifiably high? Maybe both are the case. Physics has a long tradition for being looked upon as difficult (Carlone, 2003; Osborne & Collins, 2001) and functions as a "gatekeeper" to prestigious higher educations such as medicine and civil engineering. It has also been claimed that physics has certain characteristics that make it "inherently difficult." Dolin (2002), with basis in Roth (1995), suggested that physics appears difficult because it requires pupils to cope with a range of different forms of representation (experiments, graphs, mathematical symbols, verbal descriptions, etc.) simultaneously and to manage the transformation between these different representations.

In the focus groups, too, physics was described as demanding and labour-intensive. Part of the trouble was often ascribed to the fact that in physics, *understanding* is essential, as opposed to other subjects where rote-learning and/or "general prattle" are necessary and sufficient. However, this situation also had positive aspects: Pupils described physics as *relieving* them from rote learning rather than as *requiring* understanding.

Boy, gr. 13: I hate just accepting too much, such as in maths (. . .) pure rote learning, as I said. (. . .) But in physics it is OK, right? Most of it is understanding.

The girls in particular regarded physics as difficult. In the focus groups, girls more often than boys stated that they had hesitated to choose physics and doubted whether they would make it through the physics courses.

Girl, gr. 12: Girls doubt their own abilities much more, I think (. . .). And we think that we are not going to make it, boys have much more self confidence.

Warrington and Younger (2000) pointed out that mathematics and science subjects are still socially constructed as masculine, and reported that girls describe physics as very difficult

and demanding. Haüssler and Hoffman (2000) found for German pupils that boys' physics-related self concept was higher than their general school-related self concept, whereas the opposite was true for girls. Moreover, they showed that pupils' interest in physic as such is something quite different from their interest in physics as a school subject. Whereas the former is predicted by variables such as fascination by technology and natural phenomena, the latter is predicted by the pupil's physics-related self concept.

In the present study, it was claimed in the focus groups that one reason why the girls found physics difficult was that girls have higher expectations regarding their *understanding* than the boys:

> Girl, gr. 13: I think maybe boys have an advantage (. . .) girls have to understand things, right? Because girls get hooked on it, whereas boys can kind of accept it more, and then they get on since they just let it lie

Stadler, Duit, and Benke (2000) claimed that boys and girls hold different notions of what it means to understand physics: Girls think they understand a concept only if they can put it into a broader world view, whereas boys appear to view physics as valuable in itself and are satisfied if there is internal coherence among the physics concepts learned. Osborne and Collins (2001) found that girls expressed a desire to know why things happened in science (the causal question) rather than simply learning only what happened (the ontological question).

Grade 12 pupils (regardless of subject) were asked to indicate degree of agreement with a number of statements about physics. In Figure 2, degree of agreement among the physics-choosers in this sample is compared to the degree of agreement among language and social science choosers. The figure shows, not surprisingly, that the physics pupils find physics more interesting than the others. All pupils agree to a great extent that physics is difficult. Physics choosers, more than their peers, agree that physics is about understanding the world and everyday phenomena. It seems reasonable that pupils trained in social science have other

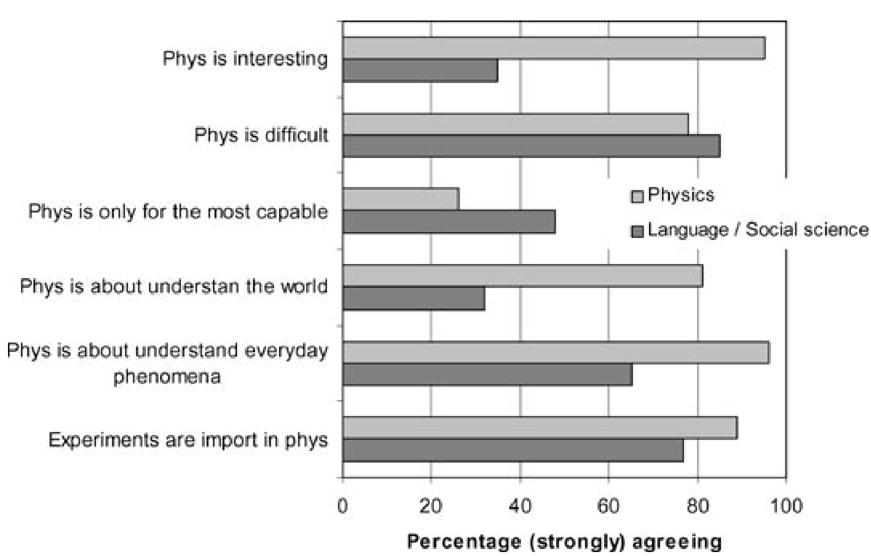

Figure 2. Grade 12 pupils' (having physics or language/social science, respectively, as their most important subject) degree of agreement to various statements about physics. Columns show the percentage of pupils marking "agree" (4) or "strongly agree" (5) on a 5-point scale. Uncertainty is ca. 8% points.

ways of approaching reality and other concepts of what it means to understand the world than physicists do. There was agreement in both groups that experiments are important in physics, a finding that contrasts with physics pupils' general low emphasis on experimental sides of physics.

Physics and "The Real World"

Pupils in the focus groups expressed that they saw physics as theoretical and abstract, but still strongly related to "the real world." However, pupils saw the grade 13 course (with relativity, quantum physics, and astrophysics) as having stronger relations to the everyday world than the grade 12 course (which is dominated by mechanics, electricity, and waves). It seems that when pupils describe physics as related to the "everyday world," they refer to their everyday conversations and "existential speculations" rather than the phenomena they observe. Relativity and quantum physics are issues which sometimes emerge in conversations (also among non-physicists) and which fascinate and mystify, and astrophysics has implications for the individual's view of his or her own place in the order of the universe. Thus, pupils (paradoxically?) see these issues as more relevant to their everyday lives than acceleration, friction, and current. This may be related to the growing alienation from everyday technology: Whereas some decades ago, it was natural for a person trained in physics to repair cars and radios, today most technological products are built from "black boxes" and microchips and cannot be understood even by persons trained in physics.

One of the favourite issues that came up during focus groups was the theory of relativity. Pupils liked discussing relativity for two reasons. First, they (especially the boys) enjoyed the intriguing implications of the theory; second, they enjoyed having "expertise" in a topic that sometimes emerged during everyday conversations. This social element of physics knowledge appeared especially important for the girls and helped them relate physics to the "everyday world."

Girl, gr. 13: ..it is quite fun, that theory of relativity. I got quite fascinated.

Girl, gr. 13: I have explained relativity theory to several people, but then they all gave me stupid looks when I ...

Girl, gr. 13: (laughing) Yeah, right!

Along similar lines, Osborne and Collins (2001) found that British 16-year-olds (especially girls) emphasized the importance of science for understanding the world and explaining things to other people.

Mathematics in Physics—A Problem?

Pupils and teachers were asked to rate various aspects that might pose problems to pupils in physics.

Figure 3 shows that, again, the high workload (extensive curriculum, fast progression) is what pupils see as the main problem. "Using mathematics to describe physical phenomena" was also rated as (very) difficult by 1/4 of the pupils, whereas only 10% of the pupils saw "using maths to solve physics problems" as (very) difficult. Not surprisingly, the pupils with the highest grades saw all aspects as less problematic than their peers. There were no significant gender differences except for the item "see the connection between physical theories and the real world," where girls saw this as more problematic than boys. Very few

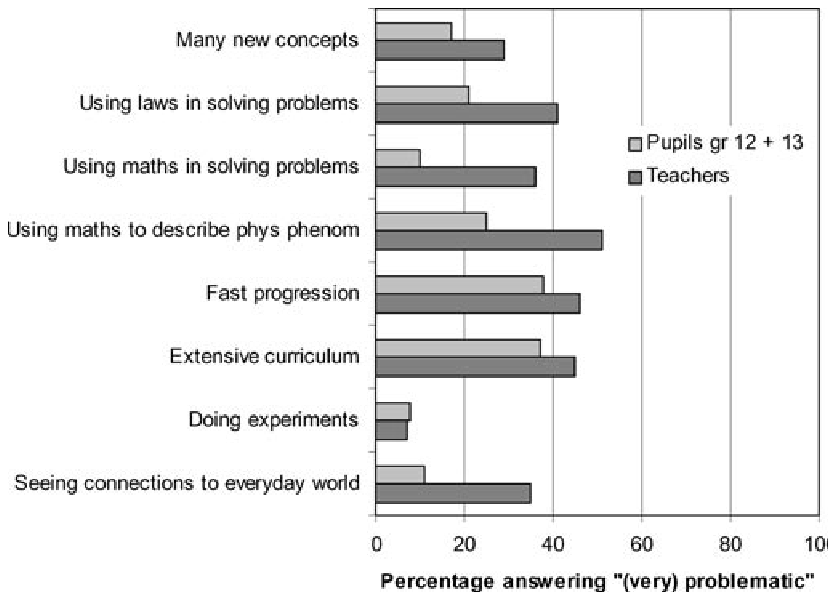

Figure 3. What is problematic in physics? Columns show the proportion of pupils and teachers who rated each aspect as "problematic" (4) or "very problematic" (5) on a 5-point scale. Teachers' ratings regarded what they perceived their pupils to find problematic. Uncertainty in pupil data is ca. 2% points.

pupils saw doing experiments as problematic. Figure 3 also shows how teachers rated their pupils' difficulties as they perceived them. It appears that teachers tend to exaggerate their students' difficulties—an indication of teachers' high expectations for pupils' performance, especially regarding use of mathematics?

It seems to be a widespread problem that teachers complain about physics pupils' mathematical skills (EVA, 2001; Gill, 1999; Neuschatz & McFarling, 1999), and poor preparation in mathematics is seen as a problem also in higher education within science and engineering (Drury & Allen, 2002; Orton & Roper, 2000). However, pupils in our study did not see lack of mathematical skills as a serious problem for them in physics.

Pupils in the focus groups described mathematics in physics as "simple and uncomplicated calculations," and they maintained that "everyone knows enough maths to do calculations in physics." However, some quotes from the focus groups indicate that pupils may have some trouble with mathematics although they did not acknowledge it when asked directly. For instance, they criticized the teachers for not showing details of the calculations when doing problems on the blackboard.

Boy, gr 12: If there are (..) teachers who complain that we do not know the maths, then at least they should show us

Pupils admitted that they were not very good at combining formulas and doing calculations with symbols instead of numbers. Also, combining two or more formulas to solve a problem caused trouble for pupils. It seems that it is the "translation" from a physical situation to a mathematical expression that causes trouble. When watching the teacher doing calculations on the blackboard, pupils realize that the algebra itself is simple; however, they lack the experience to perform all the operations—finding the right formula(s) and doing the necessary manipulations—themselves.

Boy, gr. 12: When we have (. . .) two or three formulas that have a connection between them, and then we had to do some calculations on them and do some changes and such. We are not so good at that.

Moreover, pupils expressed that it was hard to keep the various expressions and formulas apart, especially since some of the same symbols appear in different contexts (such as W for work and W for watt).

All in all, however, pupils in the focus groups seemed to appreciate that the language of physics is mathematics and that mathematics is a useful tool for shedding light on physical processes and phenomena: They expressed that physics provided opportunities for using mathematics in interesting ways. Many pupils in the focus groups suggested that the necessary mathematics should be taught within the physics course.

What is Interesting, Important, and Characteristic in Physics?

In the questionnaire, we asked physics pupils to indicate their interest in various topics from the curriculum and also their interest in experimental work and historical/philosophical dimensions of physics. It appeared that, on a scale from 1 (not interesting) to 5 (very interesting), all topics except the historical/philosophical dimension had an average score higher than 3 (neutral). Astrophysics and relativity scored highest of all (Figure 4). Similarly, astronomy and space were found to generate universal enthusiasm among British 16-year-olds (Osborne & Collins, 2001).

There was a small, but significant gender difference in interest for two of the topics such that girls preferred light and waves whereas boys preferred electricity.

Figure 4 also shows that teachers tended to exaggerate their pupils' interest or lack of interest in various topics. This may indicate that they are sensitive to pupils' reactions to the various parts of the curriculum.

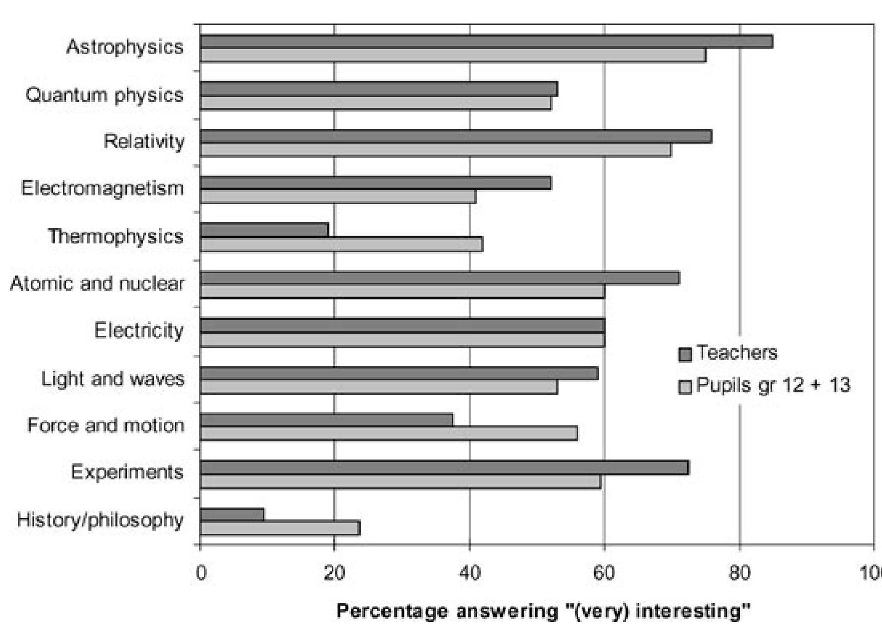

Figure 4. The percentage of pupils rating each physics topic as "interesting" (4) or "very interesting" (5) on a 5-point scale, and the percentage of teachers rating pupils' interest as they perceive it on the same scale. Uncertainty for pupils is 2% points.

In the questionnaire, we asked pupils and teachers to rate the importance of various aspects of physics. Aspects having to do with understanding the world and everyday phenomena were rated highly by both groups (Figure 5). It should be kept in mind here that pupils' meaning of "everyday physics" is very wide, as discussed above. Girls put significantly more emphasis than boys on understanding phenomena, forming reasoned opinions on science-related matters, and understanding the world—again showing their orientation towards taking their physics knowledge into the real world and everyday life.

Pupils' and teachers' ratings differed markedly in two respects. First, teachers rated experimental work (using measuring equipment, experiencing exciting experiments) higher than pupils did; second, teachers rated "doing calculations from basic laws of nature" higher than pupils did. None of the groups rated knowledge of the history of science as important. This is in contrast with findings from the focus groups, where especially girls would like more focus on the historical-philosophical dimensions of physics.

From a factor analysis of pupils' responses to all items in the two questions "what is interesting in physics" and "what is important in physics," four factors were extracted. For each factor we conducted a reliability analysis and removed those two items that reduced the alpha coefficient ("learn to use measuring equipment" and "forming opinions about nuclear power etc."). The first factor, "topics," included all the topic items in the interest-question (electricity, thermophysics, relativity and so on). The second factor, "understanding our world and basic laws," included the items from the importance-question having to do with understanding the world and everyday technology and doing calculation from basics laws. The third factor, "history/society," included one item from each question concerning historical and philosophical aspects. The fourth factor, "experiments," included one item from each question concerning experimental work. These four factors accounted for 54% of the total variance. The factors and corresponding items and reliabilities are reported in Table 2.

If we look at the correlations between the pupils' score on each of these factors and their grades, it appears that those with the highest grades score highest on the "topics" and

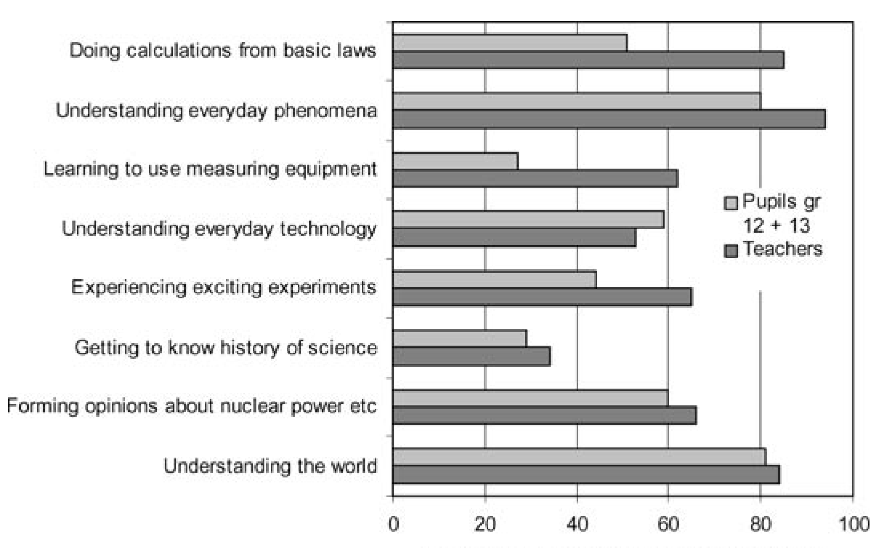

Figure 5. Pupils' and teachers' rating of the importance of various aspects of physics. Columns show the percentage of respondents rating each aspect as "important" (4) or "very important" (5) on a 5-point scale. Uncertainty for the pupils is ca. 3% points.

TABLE 2
Results from a Factor Analysis of All Items from the Questions Concerning What Is Interesting and Important in Physics (see Figures 4 and 5)

Factor	Cronbach α	Included Items
Topics	0.70	Astrophysics
		Quantum physics
		Relativity
		Electromagnetism
		Thermo physics
		Atomic and nuclear physics
		Electricity
		Light and waves
		Force and motion
Understanding our world and basic laws	0.68	Calculation from basic laws
		Everyday phenomena
		Everyday technology
		Understanding the world
History/society	0.65	History of science
		History/philosophy/interaction with society
Experiments	0.71	Exciting experiments
		Experiments

"understanding our world and basic laws" factor, whereas those with the lowest grades score highest on "history/society" and "experiments." The correlations are reported in Table 3.

This may indicate that the most well-adapted pupils in today's physics classes are those who comply with the traditional paradigm for physics teaching: Pupils with an orientation towards "physics content and basic laws" are rewarded with the highest grades, whereas pupils oriented towards "physics history, contexts, and processes" do not receive the same acclaim.

Also pupils in an evaluation study of Danish high school physics (EVA, 2001) appeared to have a largely "traditional" view of the physics subject in the sense that they emphasized the concepts, laws, and calculations and paid less attention to human, historical, and social aspects of science. The strong, traditional view of physics as difficult, objective, etc. was also discussed by Carlone (2003).

In the questionnaire, pupils and teachers were given an open question about what they saw as most characteristic of physics as a subject. Only 1/3 of pupils and nearly 2/3 of teachers

TABLE 3
Correlations Between Pupils' Physics Grade and Their Score on Each of the Four Factors from the Factor Analysis Presented in Table 2

	Grade
Topics	0.22[a]
Understanding our world and basic laws	0.13[a]
History/society	−0.07[a]
Experiments	−0.09[a]

[a]Pearson correlation is significant at the 0.01 level.

responded to this question. The most frequent answers from pupils concerned the formalistic and mathematical nature of the subject ("formulas, laws, theories, calculations/maths") and physics as "describing or explaining the world" (Figure 6). Both these characteristics were also frequently mentioned by the teachers. Again, teachers put more emphasis on the experimental nature of physics than the pupils did (hardly any of the pupils mentioned this in their responses). Girls mentioned physics as "explaining the world" relatively more often than boys in their responses, whereas boys mentioned "interesting" relatively more often.

In the focus groups, pupils touched on the idealized model of reality that physics represents. A few expressed frustrations; they had anticipated "learning about reality" and were instead presented with models with sets of given laws.

> Boy, gr. 13: I lost some interest in grade 12 when it was emphasized that this is only a model and reality isn't like that.

They apparently did not see an idealized model as an explanation of phenomena. A few pupils, however, showed considerable abilities of abstraction:

> Girl, gr. 13: [Physics is] reality in another way, you might say
>
> Girl, gr. 13: You don't discuss reality as it is, but in a way what lies behind

Pupils' understanding of scientific models and the need for a greater emphasis of teaching the role of models in science have been discussed by, for instance, Grosslight, Unger, and Jay (1991) and Treagust, Chittleborough, and Mamiala (2002).

The Role of Experiments. Figures 5 and 6 indicate that pupils do not see experiments as either important or characteristic for physics. On the other hand, many pupils find "doing experiments in physics" interesting (see Figure 4). Pupils' relation to experimental work was

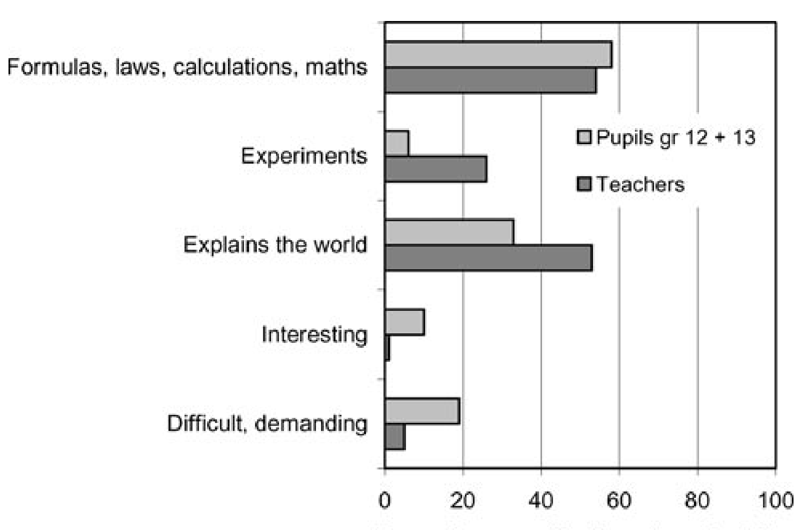

Figure 6. "What I see as most characteristic of physics as a subject is...." The figure shows the prevalence of different categories of responses to this open question from those who did respond. Some responses were coded into more than one category.

investigated in the focus groups. It appeared that pupils saw the main aim of experimental work in school science as "showing the theory in practice."

Boy, gr. 12: It makes the formulas more clear.

Girl, gr. 12: That ampere box, it is not exactly a circle with an A on it, so it is quite good that one gets to see what it really looks like

Although laboratory work was generally not seen as a source of new knowledge for the pupils, some pupils expressed that experiments could give new insights and challenge prior understanding. Pupils also said that experiments could help making physics concepts more clear. Many pupils preferred teacher demonstrations to pupil activity since the latter was perceived to create chaos. Pupils also preferred having the theoretical background in place *before* doing the experiment or watching the demonstration. A similar finding was reported by Sadler and Tai (2001). Séré (2002) warned against the view of labwork as serving conceptual knowledge exclusively, and called for a stronger emphasis on process goals and goals related to understanding the nature of science.

It seems that experiments in physics lessons appear to pupils as "fun and easy", but that they do not succeed in illustrating for pupils the central role that experiments have in the development of physics and natural science. Similarly, Seidel, and Prenzel (2002) noted that in German school physics, experiments do not have the intended function in students' learning process. Leach (1999) and Ryder et al. (1999) reported that pupils as well as undergraduate students had an incomplete understanding of the role of experimental work in science.

What Happens in Physics Classrooms, and What Would Pupils Like to Happen?

To get an impression of what goes on in the average physics classroom and how pupils feel about this, the questionnaire contained a question asking pupils and teachers to indicate how frequently a number of different teaching strategies were applied in the physics course they were presently working with. Pupils were also asked to indicate how frequently they *would like* the various strategies to be applied if they could choose. The strategies included "lectures" at the blackboard, group discussions of new concepts, demonstrations to illustrate new concepts, individual problem-solving, problem-solving in groups, and so on.

Figure 7 shows that pupils and teachers agree on many points about what actually takes place in the physics classroom; for instance: pupils' suggestions are seldom used to plan teaching, demonstrations to illustrate concepts or phenomena are quite frequent, and experimental work for pupils is done from "cookbooks" and not designed by pupils. Teachers and pupils also disagree on a few points; for instance, teachers indicate that they present lectures or calculations at the blackboard to a relatively small extent and emphasise qualitative discussions of concepts to a greater extent, whereas pupils claim that the opposite is the case!

If we look at what pupils experience in relation to what they would like, we again see that pupils are relatively satisfied with many aspects of the instruction they receive; for instance, pupils express that experiments are and should be done after "cookbooks" and that project work and the use of extra literature in addition to the course book are and should be infrequent. However, there are also some interesting differences between the situation as pupils perceive it and the situation they would like. Some of the largest gaps concern teaching methods that may be termed "qualitative": emphasis on qualitative

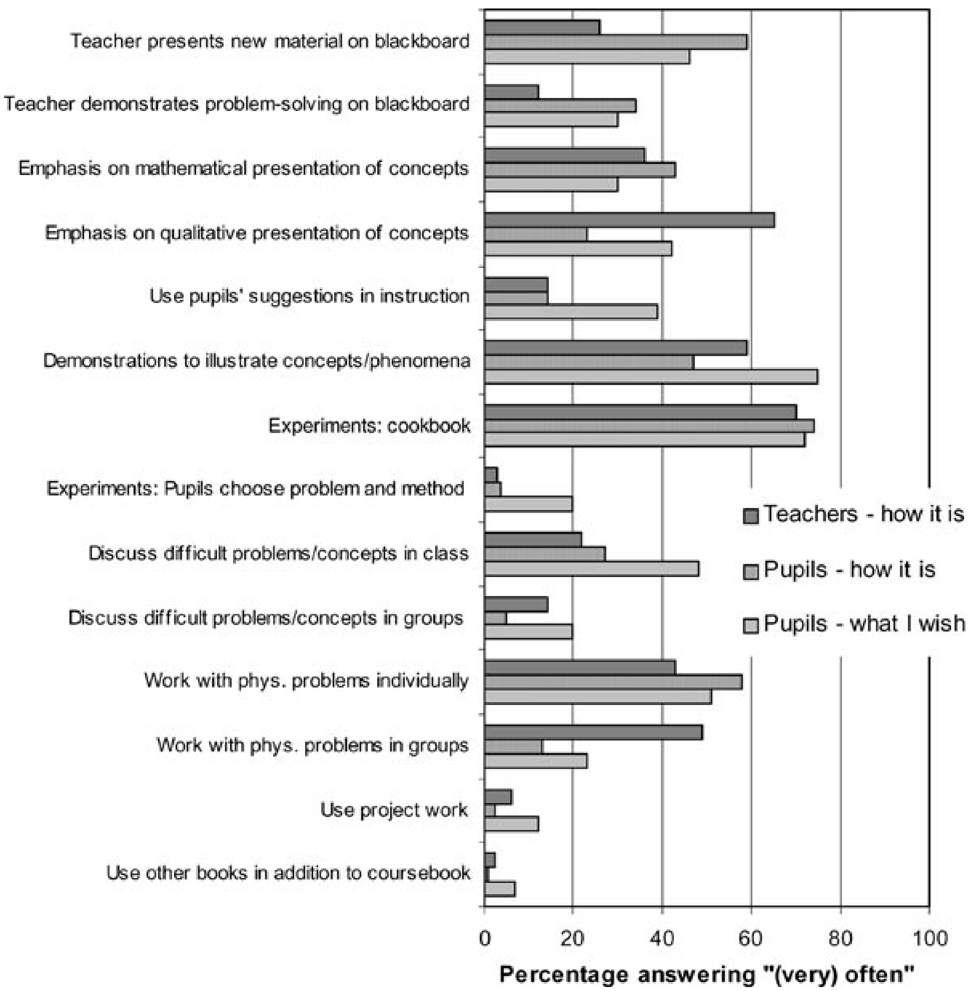

Figure 7. Pupils' indications of what actually takes place in the physics classroom ("how it is" and what they would like to happen ("what I wish"), and teachers' indications of what takes place. Columns show the percentage of respondents rating each teaching strategy as occurring "often" (4) or "very often" (5) on a 5-point scale. Uncertainty in pupil data is around 3% points.

presentation, discussion (in class or in smaller groups) of qualitative aspects of new concepts, and demonstrations to illustrate concepts. Factor analysis showed a relationship between these (Cronbach $\alpha = 0.56$). Factor analysis also showed a correlation between what may be termed "pupil-centred teaching methods": using pupils' suggestions in the lessons, letting pupils choose problem and method in experiments, problem-solving in groups, project work, and the use of additional literature (Cronbach $\alpha = 0.66$). Pupils would like instruction to be a bit more pupil-centred. Gender differences in how pupils perceived and wanted physics instruction were generally small; however, girls were significantly more positive than boys to "cookbook" approaches to experiments. Also, the differences between "how it is" and "how I wish" for the "qualitative scale" and the "pupil-centered teaching methods scale" were larger for girls than for boys. Although the tendency is weak in our sample, it is in accord with Warrington and Younger's (2000) claim that classroom processes tend to alienate girls.

Physics teaching was also broadly discussed in the focus groups. The pupils displayed considerable maturity regarding their own responsibility for learning; they claimed that good or bad physics lessons largely depended on their own enthusiasm and engagement (or lack of such). Whereas the questionnaire results indicated that pupils would like more qualitative teaching methods (see above), pupils in focus groups largely expressed that their teachers emphasized qualitative explanations and understanding sufficiently. Some expressed that physics is mathematical, but that this is unavoidable and inherent in the nature of the subject.

> Boy, gr. 13: The problem is that some of it has to be boring, 'cause it doesn't really help to just go through it once, you have to do a lot of problems, calculations and such.

However, some grade 13 girls expressed that new concepts should to a greater extent be expressed in words. This related to their previously mentioned greater need to "understand" phenomena in a sense that enabled them to relate their physics knowledge to the "outside world" and use it in everyday conversations.

Stokking (2000) found that physics pupils in the Netherlands wanted a stronger orientation of physics towards everyday life and teaching methods that supported active participation. Labudde et al. (2000) suggested that exactly these factors would be effective at improving girls' experience of (and therefore choice of) physics. Wistedt (2001) found that Swedish university technology programmes that succeeded in recruiting and keeping female students were characterized by cooperation-based and problem-oriented methods and by rich opportunities for interaction between students and between students and staff.

Numerous studies have pointed to the essential influence of the teacher on pupils' attitudes to the subject and the teaching (Nolen, 2003; Osborne & Collins, 2001; Sadler & Tai, 2001). In one of the focus groups, pupils from two separate classes with different teachers discussed the instruction. It appeared that the two teachers used very different methods, but both groups of pupils were satisfied with their own teacher and maintained that he gave the best instruction. This reinforces the impression that pupils adapt strongly to the teaching they actually do receive.

When asked what characterized a good physics lesson, pupils in focus groups agreed that variation was an important keyword. Likewise, Danish physics pupils expressed that variation was essential in good physics instruction (EVA, 2001). Seidel and Prenzel (2002) saw instructional quality as "an orchestration of various didactic approaches" and claimed that a wide repertoire of teaching methods used flexibly was a relevant indicator for student learning. Kempa and Diaz (1990), on the basis of variations in pupil motivational traits, similarly recommended greater variation in instructional methods.

To investigate whether the instructional methods in physics classrooms were different from those employed in other subjects, we asked the grade 12 pupils (regardless of subject of specialization) to answer a question about the frequency of various teaching methods (the question was more general than the corresponding question to the physics pupils in order to apply to all the various subjects). The method "teacher presents new material at the blackboard" ("chalk and talk") is (according to pupils) more frequently used in the natural sciences than in english or social science (Figure 8).

Students in all subjects except english wish somewhat less "chalk and talk," but the difference between how it is and what pupils wish is only significant for mathematics and physics. All in all, what is perhaps most striking about Figure 8 is how well most pupils seem to adapt to the instruction they are actually offered.

The pupils in the focus groups expressed that "chalk and talk" approaches were boring, whereas discussion was seen as a means of making difficult subject matter more

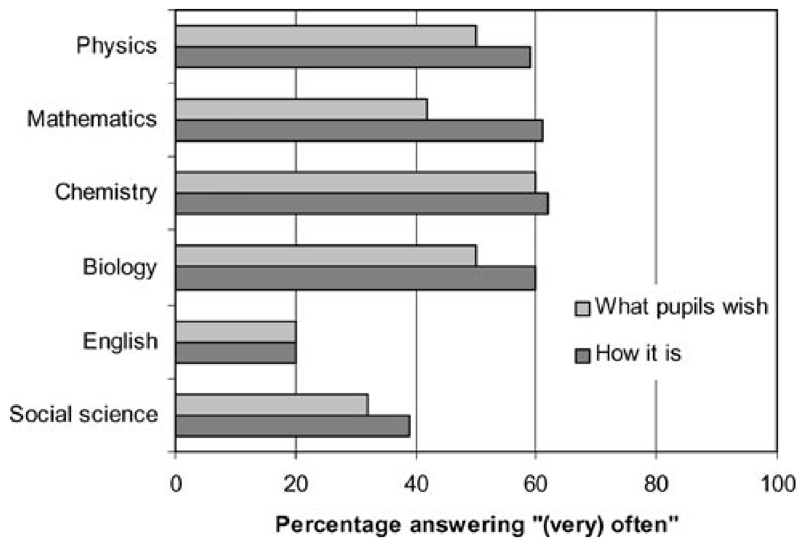

Figure 8. Grade 12 pupils' rating of how frequently the teacher spends most of the lesson presenting new material on the blackboard in their subject of specialization, and how often they would like this to happen. Columns show the percentage of pupils rating this as happening "often" (4) or "very often" (5) on a 5-point scale. Uncertainty is ca. 5% points.

understandable. Interesting stories concerning the topic to be covered were also popular. Despite appearing very focused on covering the curriculum in order to do well on the final exam, pupils appreciated discussions of physics-related issues far outside of the curriculum.

Girl, gr. 13: . . . like when we were doing astronomy, right, or astrophysics, it was really exciting. Then I talked about "oh, maybe there are people on other planets" and such.

It seemed hard for the pupils to imagine alternatives to the teaching they received; they viewed the subject matter as relatively fixed and the instruction methods as largely determined by the nature of the subject matter (see quote above, ".. some of it has to be boring.."). The pupils appear very "conservative" in their view of learning and their attitude to alternative teaching methods and curricula. During the last few decades, the constructivist view of learning has been prevalent within the science education community. This view emphasizes the active role of the learner and "reduces" the role of the teacher to that of facilitator for the pupils' learning process. However, such a view appears to be very far from pupils' perception of the teaching-learning situation. For instance, pupils in the focus groups expressed that physics was a subject that was impossible to learn on one's own; they were dependent on the teachers "explaining it to them." Similarly, Geelan (1997) and Carlone (2003) have pointed out how the prevalent school science culture and the expectations of students, parents, and teachers inhibit the implementation of new teaching approaches.

SUMMARY, IMPLICATIONS, AND CONCLUSION

Portrait of a Subject: Physics as a Closed System

In summary, physics is perceived by pupils as interesting, but demanding; formalistic in nature, but still describing the world and everyday phenomena. Girls have somewhat

different demands for their understanding than boys and emphasize context and connectedness more. Pupils, especially girls, seem to feel that "exotic" topics like relativity and astrophysics are closer to their life-world than mechanics, electricity, etc. Whereas teachers complain about pupils' poor mathematics skills, pupils do not see this as a major problem. In physics instruction, "traditional physics content knowledge" is emphasized over experimental, historical/philosophical, and science/society approaches, and the subject seems to attract and reward pupils with this traditional orientation. Pupils seem to have a relatively weak understanding of the central role of experiments in science. Pupils are largely in line with their teachers concerning instructional approaches in the physics classroom; however, pupils would like a somewhat stronger emphasis on qualitative/conceptual approaches and student-centred instruction. Variation was seen as essential in good instruction. Generally, pupils appear conservative in their views on teaching and learning. Gender differences throughout this study are surprisingly small; however, they were more readily discernible in the focus group study than in the questionnaire results.

From our data, it appears that physics is different from other school subjects (notably english and social science) in that it has a higher workload and a faster progression and is more conceptually demanding. Also, pupils express that physics requires understanding; rote learning is not sufficient. Physics lessons are dominated by "chalk and talk" instruction.

Whereas the present form of school science has been criticized (Osborne & Collins, 2001; Sjøberg, 2002; Warrington & Younger, 2000), the physics pupils in our study appear to be happy with it. New trends in science education, allegedly based on research and advocated by science education researchers, may be lumped under headings such as "science for all," "widening perspectives," "the nature of science," "the importance of context," "STS," etc. (Sjøberg, 2002). It is ironic, then, that the pupils in this study largely embrace the traditional instruction methods: teacher "explanations," individual problem-solving, etc., and have little regard for methods like project work, open-ended experiments, historical and philosophical sides of physics, and so on. Today's system seems to encourage interest in narrow, traditional physics content.

Similarly, Osborne and Collins (2001) described the British science curriculum as having "a foundationalist emphasis on basic concepts," and they remarked that "science education has remained fundamentally an education for science rather than an education about science, dominated by (. . .) the needs of the scientific establishment . . . ."

The picture that emerges of Norwegian physics pupils and their teachers is that they represent a "closed system" where both parties seem to get the subject they want. Pupils appear quite conservative, they are satisfied with the subject and the instruction, and have few wishes for change. The teachers on their side get interested and motivated pupils who are very much like themselves.

Is this situation representative for school physics in general, or is it special for Norway? If the latter is true, are there features of the Norwegian society and school system that can explain the situation? We will argue that the situation is fairly general. The previous discussion with its international comparisons has shown that many of our findings fit into a pattern (termed "prototypical physics" by Carlone, 2003) describing school physics as it appears in many Western countries.

Maybe the most striking characteristic of Norwegian school physics as we have described it is the high degree of satisfaction with status quo. Authors describing school physics or school science in other countries have reported somewhat stronger criticisms, see for instance Osborne and Collins (2001) and Häussler and Hoffman (2000). Also in the TIMSS study, Norwegian physics pupils were among the most satisfied and highest-achieving (Mullis et al., 1998).

The high degree of satisfaction among Norwegian physics pupils and teachers may be attributable to a number of causes, for instance:

- Highly qualified teachers?
- Relatively "modern" curriculum in terms of topics and emphases?
- Biased selection of academically high-achieving pupils aiming at prestigious higher education?
- Biased selection of pupils from science-friendly and academically oriented backgrounds (Turmo (in press) has shown that Norwegian pupils' scientific literacy is surprisingly strongly related to their "cultural capital")?

Since all appears to be well inside the closed system of school physics, is there any need for concern? The answer must be yes, since the number of physics pupils is too small to cover estimated future demands for a skilled labour force, maybe also too small to ensure a sufficient number of informed citizens in a democracy (Drury & Allen, 2002; EPS, 1999; Jørgensen, 1998). Thus, it seems that new groups of pupils have to be recruited from outside the closed system.

The Road Ahead

The crucial question is whether we still want a physics subject for the few or whether we want to recruit new and wider groups of pupils. From prognoses of future demands on the labor force, it seems that we have little choice; recruitment of new groups is essential.

How may this be done? There are two main types of recruitment projects: Those that aim to open more pupils' eyes to the wonders and advantages of physics as it is, and those that aim to change the subject (contents, instructional methods, emphases) in order to keep pupils on the "science track" and attract new groups. Both approaches may have some effect; however, the data from the present study are relevant mainly to throw light on the second one. Moreover, regarding the recruitment of girls, who represent the greatest recruitment potential, Wistedt (2001) found, after a study of "gender-inclusive" university programmes in science and technology, that there is a need for radical experiment with the contents of the educational programs, rather than recruitment campaigns to convince female students to enter existing programs.

For a physics curriculum designed to keep pupils in science and technology and attract new groups, the following recommendations may be given based on our findings:

- Make the subject less demanding and work-intensive compared to other subjects, for instance by reducing the number of topics to be covered
- Emphasise science knowledge in context
- Use more qualitative/conceptual discussions and demonstrations
- Make the role of experiments more clear
- Integrate mathematics in the physics course
- Provide variation in teaching methods

If such changes were implemented in school physics—how would these changes be received by those who are presently satisfied with the subject—the pupils and (maybe more importantly?) the teachers who are to administer the courses to new generations of pupils?

There seems to be a need not only for variation of teaching methods, but also for a variety of physics *courses* tailored to the interests, plans, and inclinations of various groups of pupils. In its report "Maintaining Momentum" (Neuschatz & McFarling, 1999, p. iii), the

American Institute of Physics noted that "the high school physics curriculum has grown more varied, moving away from the one-size-fits-all course that predominated a decade ago, to encompass courses designed to accommodate students with varying mathematics backgrounds and academic aspirations."

The American high school curriculum "Minds-on Physics" has "less is more" as its philosophy and aims to have students build solid conceptual understanding within a few chosen topics (mostly mechanics) considered to be basic and essential. However, in a study of the preferences and priorities of teachers involved in the course, it emerged that while teachers saw a "less is more" course based on mechanics as very suitable for pupils who were going on to a higher education in science or technology, they did NOT find it suitable for pupils who would not work with physics after high school. For the latter, a survey course that familiarizes pupils with a variety of topics was considered recommendable (Feldman & Kropf, 1999).

Given the conservatism in the school physics community, changes can not be expected to occur overnight as a straightforward result of curriculum changes. In order for pupils' attained curriculum (Goodlad, 1979) to change, teachers must change their mentality as well as their classroom practices. In this process, organized in-service training is probably required. However, the need for a change of attitude is not restricted to the teachers. Geelan (1997) remarked that if changes are to occur, ". . . it will not be because teachers have unilaterally chosen to change their own roles; rather, it will be through a process of negotiation and role redefinition that includes all stakeholders, including parents."

CONCLUSION

In order to tailor upper secondary physics education to the needs of future professionals and citizens, it seems advisable to offer *variety* both within and among courses. Thus, we expect the American move away from the "one-size-fits-all" to appear also in Europe and elsewhere. In our own country, Norway, there may be a need for at least two different upper secondary physics courses, one for "future engineers and researchers" and one for "everybody else who is interested." Moreover, to improve pupils' profit from any type of physics course, important keywords are variation in instruction, integration of mathematics in the course, subject matter context, and clear objectives for experimental work.

Physics is an ancient science involving everything from basic philosophical questions to everyday phenomena, from nature's smallest building blocks to the most distant galaxies, from high-tech satellites to processes in the human body. Continued recruitment to physics is important—not only to secure scientific expertise and literate citizens, but also because young people deserve to take part in the elegant and intriguing system of thought that physics represents.

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